Power Vision *Engineering*

Risk of Low Pressure at Penstock Top of Pumped Storage Power Plant in Pumping Mode

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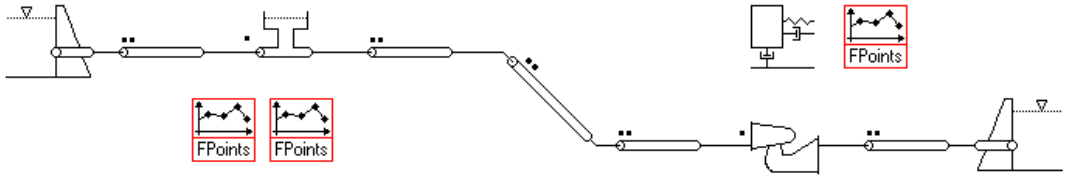
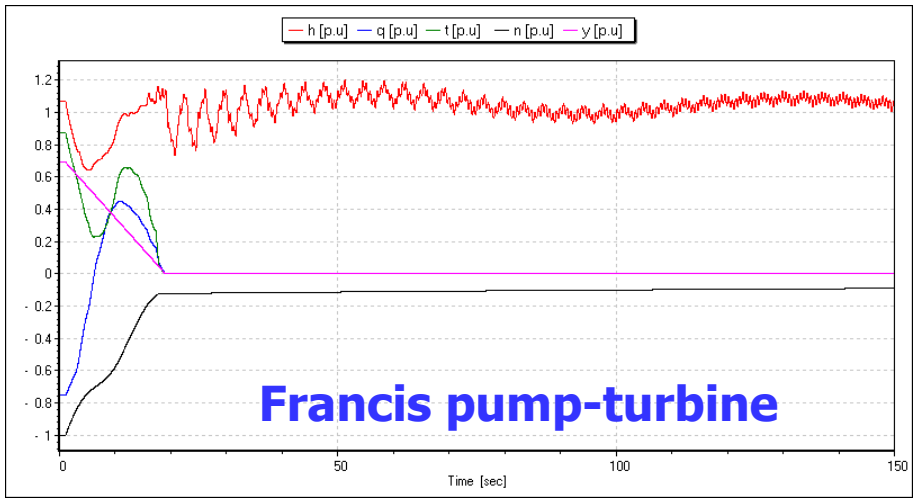
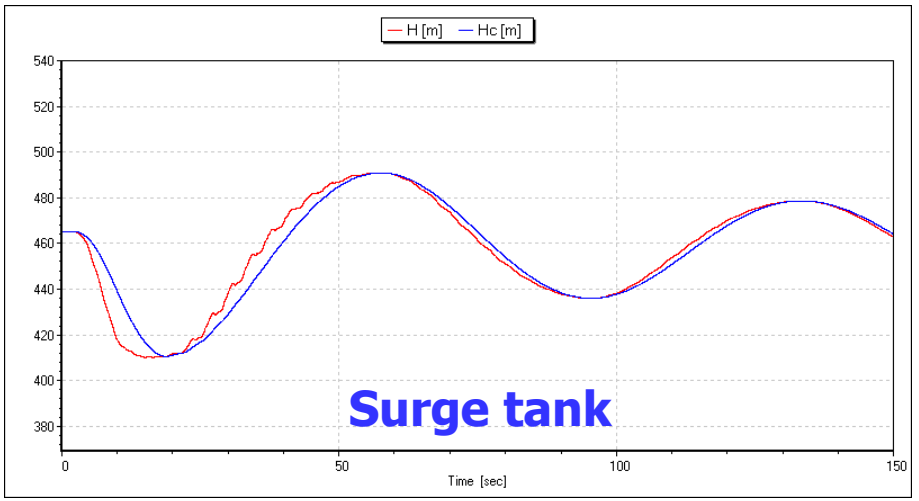
Introduction

- Risk of low pressure at top penstock in PSPP:
  - ✓ Emergency shutdown (ESD) in pumping mode:



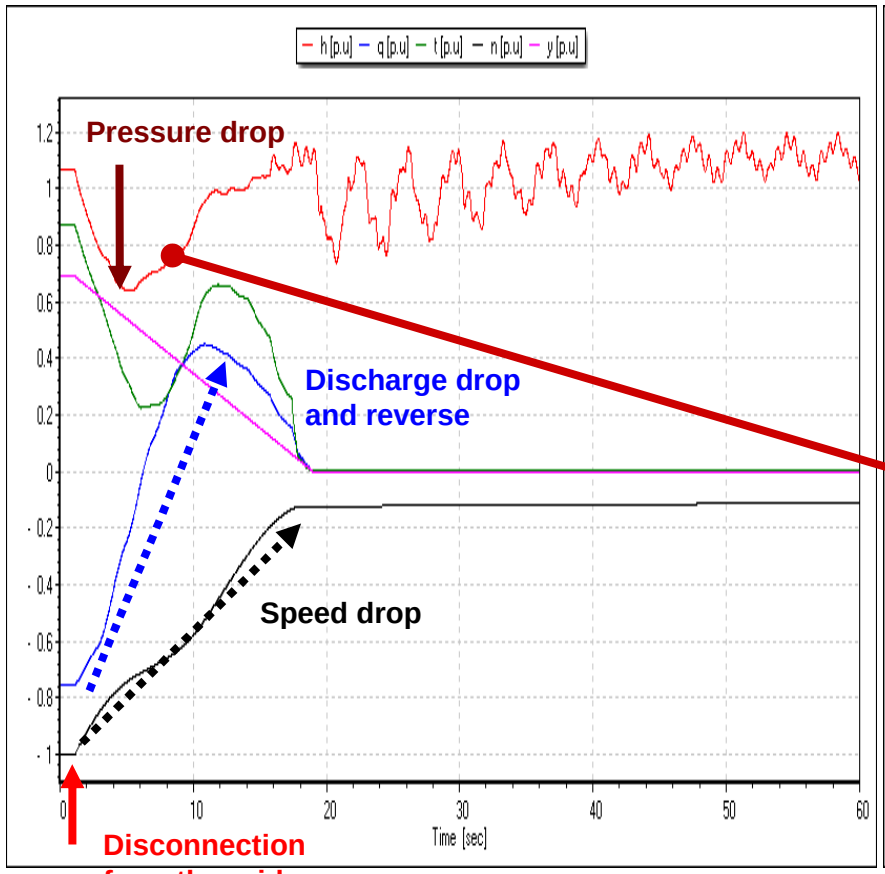
H_R [m]	Q_R [m^3/s]	N_R [rpm]	P_R [MW]	ν [-]	J [$Kg*m^2$]
440	86	428.6	340	0.26	$1.5 \cdot 10^6$

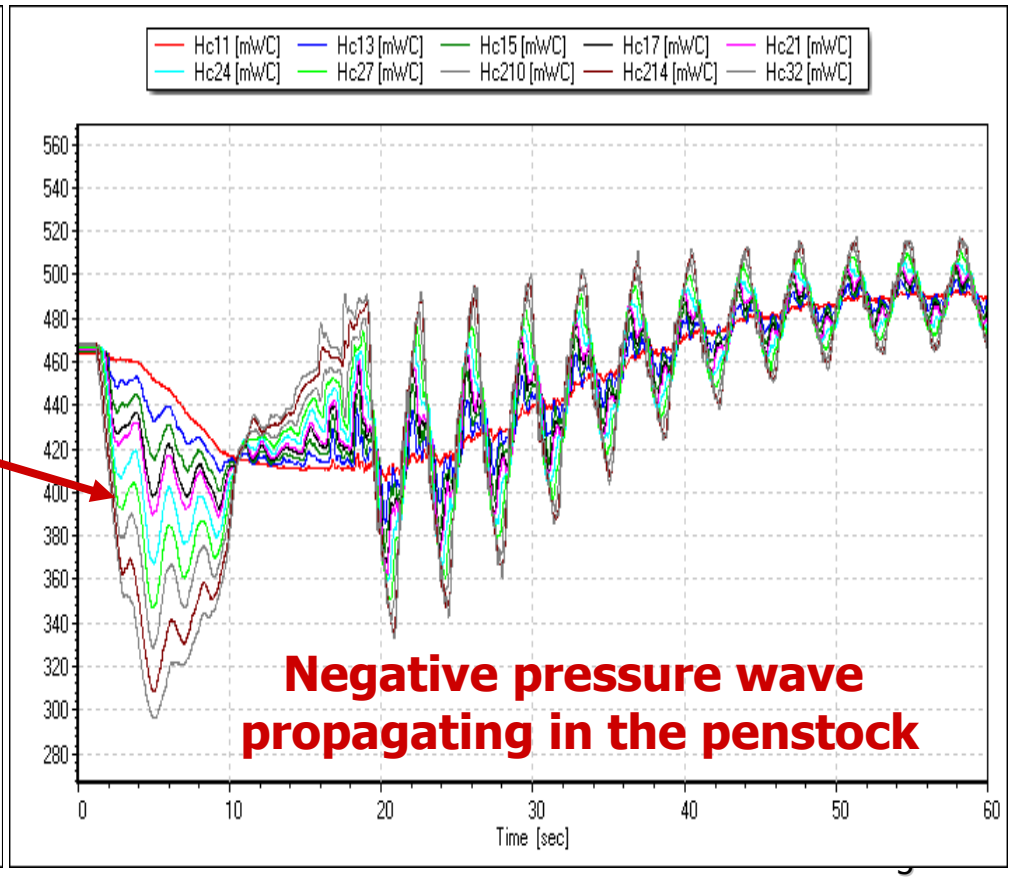




Introduction

- Risk of low pressure at top penstock in PSPP:
  - ✓ Pump-turbine detailed transient:



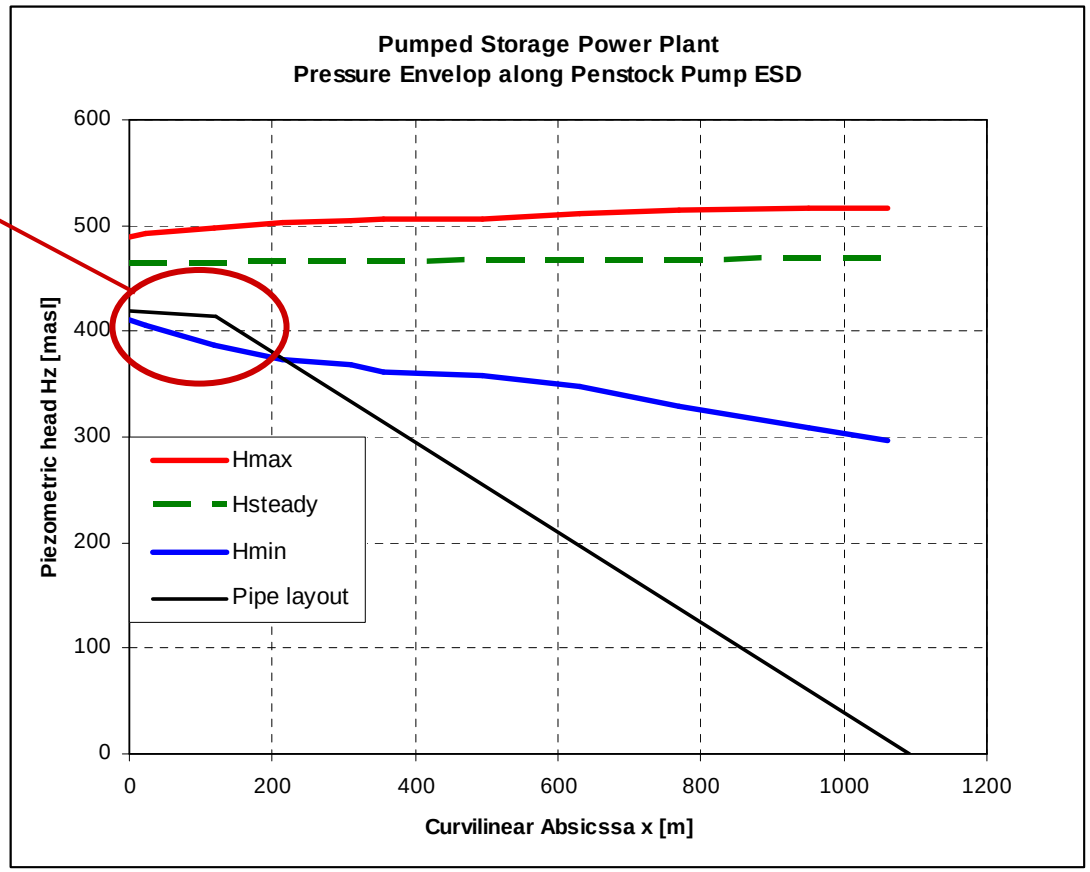


Introduction

- Risk of low pressure at top penstock in PSPP:
  - ✓ Pressure envelop along the penstock:

Low pressure at top of the penstock

Cavitation or/and water column separation or/and Air intake through air valves



Case Study

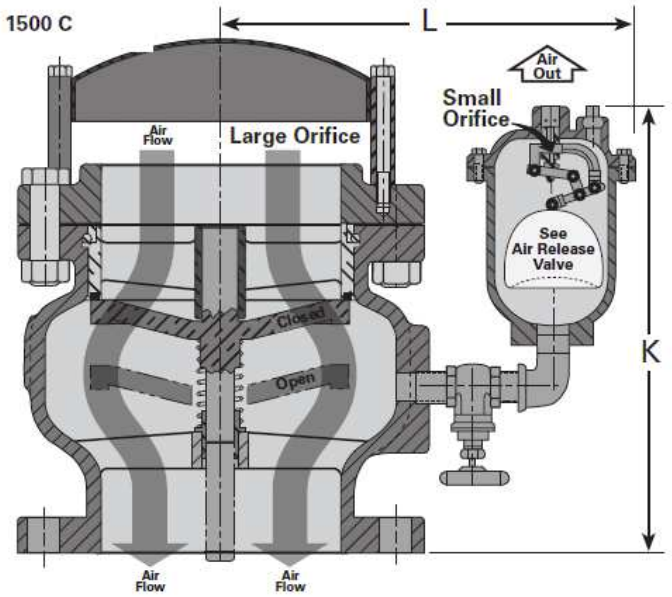
- Risk of low pressure at top penstock in PSPP:
  - ✓ Low pressure risk emphasized by:
    - High surge tank inertia $L_h = l/gA$
    - High singular head losses at junction
    - High elevation point:
      - Sub-horizontal penstock after surge tank
      - gate valve
      - air valves

Air Valves Opening

Pump Emergency Shutdown (ESD):

✓ Air valve modeling:

$$m = mo + \int_0^t \left(\frac{dm}{dt}\right) dt \qquad V = \frac{mRT}{p} \qquad pV^n = cste$$



Source: DeZurik

(Wylie & Streeter, 1993)

$$\left.\frac{dm}{dt}\right|_{in} = C_{in} \cdot A_{in} \sqrt{7 p_o \rho_o \left[\left(\frac{p}{p_o}\right)^{1.4286} - \left(\frac{p}{p_o}\right)^{1.714}\right]} \qquad p_o > p > 0.53 p_o$$

$$\left.\frac{dm}{dt}\right|_{in} = C_{in} \cdot A_{in} \frac{0.686}{\sqrt{RT_o}} p_o \qquad p < 0.53 p_o$$

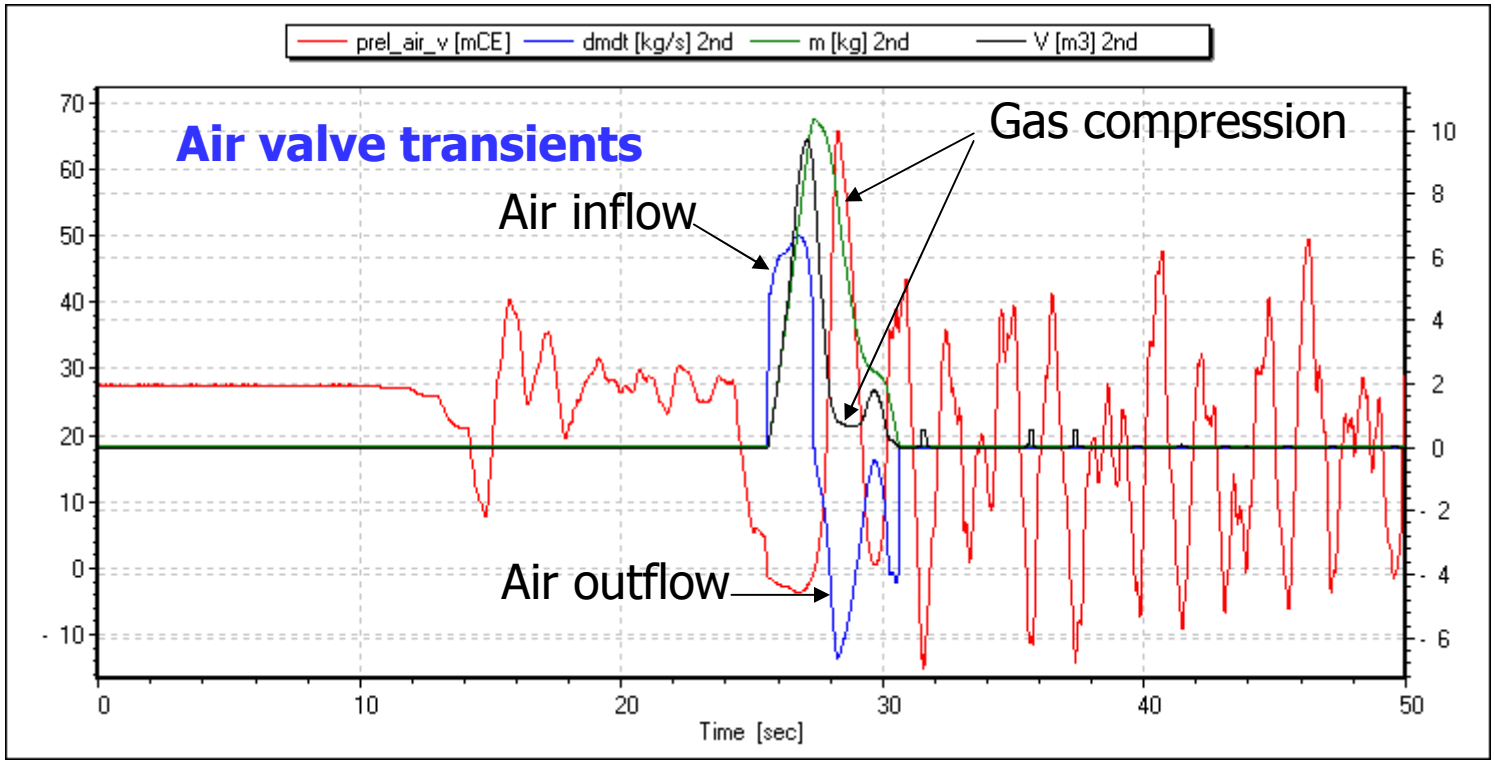
$$\left.\frac{dm}{dt}\right|_{out} = -C_{out} \cdot A_{out} \sqrt{\frac{7}{RT}\left[\left(\frac{p_o}{p}\right)^{1.4286} - \left(\frac{p_o}{p}\right)^{1.714}\right]} \qquad \frac{p_o}{0.53} > p > p_o$$

$$\left.\frac{dm}{dt}\right|_{out} = -C_{out} \cdot A_{out} \frac{0.686}{\sqrt{RT}} p \qquad p > \frac{p_o}{0.53}$$

p_o, ρ_o, T_o: gas conditions outside
R=287.6: gas constant [J/(kg·K°)]

Air Valves Opening

- Pump Emergency Shutdown (ESD):
  - ✓ Air valve modeling:



Conclusions and Recommendations

- Top penstock are subjected to low pressure in case of pump emergency shutdown
- Prediction requires detailed simulation model with realistic pump-turbine characteristic
- Surge tank may feature:
  - ✓ Inertia of the water column $L_h = {}^{l}\!/_{gA}$
  - ✓ Junction head losses
- Air valves opening at penstock top:
  - ✓ Prevent from negative pressure and cavitation if well sized (risk of penstock collapse or water column separation)
  - ✓ Also induce risk of over pressure!!! => penstock burst
- **Address carefully the top penstock pressure (min and max) with appropriate modeling including sufficient safety and error margin!**

Thank you for your attention!

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